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FEATURE PAPER

Grain spilled from moving trains create a substantial wildlife attractant in protected areas

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Abstract

Transportation corridors can attract threatened wildlife via habitat enhancement and foraging opportunities, leading to collisions with vehicles. But wildlife may also be attracted to energy-dense food products that are spilled or discarded from moving vehicles, which is rarely studied. Therefore, we quantified train-spilled attractants in Banff and Yoho National Parks, Canada, where agricultural products (hereafter, grain) are transported along 134 km of railway and may contribute to wildlife mortality. We measured grain deposition from 2012 to 2015 at 19 sites and assessed the performance of three structures developed to measure spilled grain. We then modeled grain deposition with respect to four types of spatial and temporal variables: those related to grain shipment, physical habitat characteristic, train-related characteristics and variables specific to the study site. Grain was spilled at a mean rate of 1.64 g m^{-2} day^{-1} (SD = 3.60) from April to October (n = 3 years) and 1.52 (SD = 2.37) from November to March (n = 1 year). Extrapolating annual deposition across the study area yielded enough grain (110 tons) to provide 4.77×10^8 kcal of gross energy, which is equivalent to the average annual caloric needs of 42–54 grizzly bears *Ursus arctos horribilis*; the regional population is estimated at 50–73 animals. Much of this energy will not be accessible or available to bears; however, their attraction to it could contribute to rising and unsustainable rates of mortality. Models explained 9–31% of the variance in deposition for each grain type, primarily via coarse temporal variables of shipping rates and month. The absence of more specific predictive variables suggests that mitigation should target broader policies, such as prompt reporting and repair of leaky hopper cars, and limits to train stoppage in protected areas. We encourage more global assessment of the under-studied issue of food attractants spilled by vehicles along transportation corridors.

Introduction

Numerous threatened species are attracted to sources of food created by human activity [e.g. garbage (Picton, 1978; Yirga *et al.*, 2012), carrion (Roy & Dorrance, 1985; Guinard, Julliard & Barbraud, 2012) and agricultural products (Sukumar, 1990; Naughton-Treves *et al.*, 1998)]. All of these anthropogenic foods may occur along roads and railways (e.g. Morelli *et al.*, 2014), where collisions can occur between vehicles and foraging animals [e.g. moose (*Alces alces*; Gundersen, Andreassen & Storaas, 1998); brown bears (*Ursus arctos*; Huber, Kusak & Frkovic, 1998); and birds (Erritzoe, Mazgajski & Rejt, 2003)]. Because these mortalities can reduce population viability (reviewed by Forman *et al.*, 2003), wildlife managers attempt to identify the locations and times where attractants are most prevalent (e.g. Malo, Suárez & Díez, 2004; Gomes *et al.*, 2009) to mitigate them. For example, temporary salty ponds predicted collision locations for moose (Fraser & Thomas, 1982), and proximity to water may predict collision sites for deer (*Odocoileus* spp.; Clevenger *et al.*, 2015). But attractants may not just occur along transportation networks; they may also be deposited continuously by moving vehicles. Yet, vehicle-borne attractants are rarely studied in the literature despite their likely ubiquity along transportation corridors.

A handful of authors have anticipated that attractants which are deposited by vehicles may endanger diverse wildlife species. Many of these studies involve grain (used here as a collective term for cereals, pulses and oilseeds *sensu* Canadian Grain Regulations, 2015) that is spilled during transport by trucks or trains, and to food waste that is deliberately discarded by people from passenger vehicles or trains. Grain that is spilled along roads has been suggested as a cause for collisions between vehicles and granivorous birds in India (Dhindsa *et al.*, 1988) and in Europe (reviewed by Erritzoe *et al.*, 2003). Grain spills have been

investigated as an attractant for small mammals and their predators on roads in South Africa (Ansara, 2004) and railways in Brazil (Cerboncini, Roper & Passos, 2016). Brown bears are thought to be attracted to grain that is spilled on railways in North America (Waller & Servheen, 2005; Dorsey, Olsson & Rew, 2015), and roadside garbage in Croatia (Huber *et al.*, 1998). Anecdotal observations suggest that food waste discarded from passing vehicles may attract numerous large herbivores (including chital *Axis axis* and Asian elephant *Elephas maximus*) to both roads and railways in India (e.g. Joshi, 2013; reviewed by Raman, 2011). It is likely that vehicle-borne attractants affect the distribution and abundance of numerous species, but the problem is rarely studied directly.

Food attractants spilled from passing vehicles may be especially attractive to generalist herbivores or omnivores that require large volumes of food, adapt over long lifespans to anthropogenic food sources and live in landscapes where the abundance of natural foods is limited. Grizzly bears *Ursus arctos horribilis* in Banff and Yoho National Parks, Canada epitomize these characteristics. Grizzly bears readily learn from their mothers to seek anthropogenic foods (Nielsen *et al.*, 2013); such foods may be especially attractive to bears in Banff and Yoho, because this landscape is poor in nutritional quality (López-Alfaro *et al.*, 2015). A large amount of grain has been documented to spill from trains that pass through Banff and Yoho, and attraction to this spilled grain is thought to contribute to the numerous grizzly–train collisions here (Bertch & Gibeau, 2010).

The objectives of this study were to (1) estimate the types and amount of grain deposited on the rail (i.e. between the parallel tracks), (2) determine how best to measure its deposition and (3) identify the spatial and temporal variables that predict deposition rates. We hypothesized that the deposition of grain would increase at locations and times where grain was more likely to be shaken from hopper cars or where constant leaks would be more likely to accumulate. From these hypotheses, we predicted that deposition rates would increase during time periods with higher shipping rates; at locations with greater track tortuosity or gradient; and, at locations with slower train speed, higher acceleration and with higher frequencies of train stops. We also modeled the effects of variables specific to our study site, such as sampling frequency and temporal variation (Table 1).

Materials and methods

Study area and sample sites

The Canadian Pacific Railway traverses 134 km through Banff and Yoho National Parks, which are situated in the Rocky Mountains of the provinces of Alberta and British Columbia, respectively, in Canada (Fig. 1). The railway passes through lowland habitat with high productivity in a region that is otherwise poor in resources. Trains moving toward the west carry grain for delivery to ports on the Pacific coast, which receive around 15 million tons of grain annually (much of which passes through Banff and Yoho; Alberta Agriculture and Rural Development, 2013). Since 2000, 19 grizzly bears are known to have been struck by trains in Banff and Yoho, compared to a single record between 1982 and 1999 (Parks Canada, unpubl. data) and ‘relatively few’ from historical records (Holroyd & Van Tighem, 1983).

On the basis of a power analysis of preliminary data (Whittington, 2011), we selected 19 permanent monitoring sites throughout the study area (Fig. 1), where high rates of bear activity (e.g. foraging; Fig. 1a) or mortality had previously been measured or suspected (Whittington *et al.*, 2010; Dorsey, 2011). Four of these sites contained two sets of tracks, each of which was sub-sampled for grain and were later summed. Between 2013 and 2015, we collected six grain types deposited by trains: wheat *Triticum aestivum* and barley *Hordeum vulgare*, which were combined due to their similarity in appearance and size (hereafter, referred to as wheat); canola (*Brassica* spp.), flax *Linum usitatissimum*,

Table 1 Variables used to predict grain deposition by trains passing through Banff and Yoho National Parks between 2013 and 2015

Variable type	Variable name	Spatial or temporal	Explanation
Grain transportation[a]	Grain shipment	Temporal	Amount of grain shipped via railway hopper cars in western Canada per week
	Grain delivery	Temporal	Amount of grain received at ports on the west coast of Canada per week
Physical habitat	Elevation	Spatial	Elevation at 30-m resolution
	Track tortuosity	Spatial	Computed as distance/(displacement^2) at 100, 200, 400, 800 and 1600-m resolution
	Track gradient	Spatial	Number of units of elevation change per 100 units of horizontal distance
Train characteristics	Posted train speed	Spatial	The official speed limit posted by Canadian Pacific Railway
	Measured train speed	Spatial	Mean train speed measured on the ground from 10 trains at each location
	Stoppage	Spatial	Binary variable indicating whether trains frequently stop at a location or not
	Acceleration	Spatial	Mean difference in speed of engine and the last car from five trains
Variables specific to the study site	Month	Temporal	Month of the year
	Days since check	Temporal	Days since last check of grain structure

[a]Grain delivery data were used for lentils and peas because shipping data were unavailable. Grain shipment data were used for all other grain types. These figures were used because we did not have access to data on the amount of grain that passed through our study site. Data were downloaded from Canadian Grain Commission (2015).

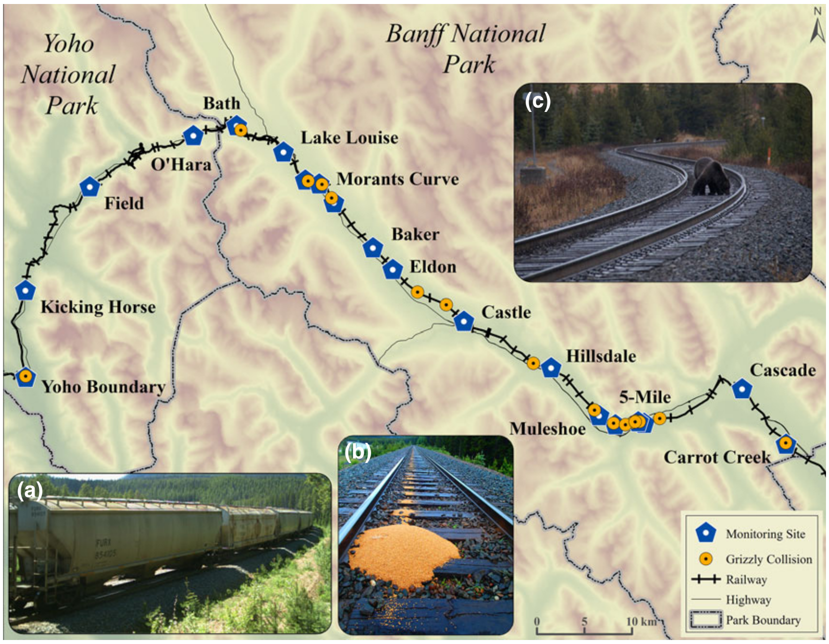

Figure 1 Map of Banff and Yoho National Parks showing locations of 19 sites where grain deposited by trains was collected between 2013 and 2015, along with photos of (a) a grizzly bear foraging on the railway track, (b) grain deposition on tracks via both spillage and trickles and (c) a hopper car carrying grain. Photo credits: Niels de Nijs, Alex P. Taylor. [Colour figure can be viewed at wileyonlinelibrary.com]

green lentils *Lens culinaris*, peas *Pisum sativum* and soybean *Glycine max*, the last two of which were combined due to their similarity in appearance and size (hereafter, referred to as peas) and canary *Phalaris canariensis*.

To evaluate whether these sites were representative of the rest of the railway, we compared the amount of grain present at 17 of these permanent sites to 16 non-permanent sites along the railway in June 2016. At each of these sites, we counted the number of grain kernels within a 10 × 10 cm quadrat, repeating this procedure 36 times within 40 m along the railway tracks (both the tie and inter-tie areas were sampled equally). We converted these counts to weights (see below), and tested for differences in grain deposition between permanent and non-permanent sites.

Methods for grain collection

Trains carry grain in hopper cars (Fig. 1b), which are loaded from the top and emptied from the bottom. Leaky hopper cars can deposit grain with spatio-temporal patterns that range from large, discrete piles (e.g. due to a broken latch) to slow, steady trickles (such as from gaps in gates or gradual spillage from roofs; Fig 1c). We anticipated that the accuracy of grain collection would be affected by (1) immediate deflection from the substrate, (2) removal after deposition by wind and turbulence, (3) removal via foraging by animals of many species, and (4) accumulation in snow layers during winter. To assess these potential effects on grain measurement, we used four types of structures to collect product samples: screen, basket, box and lid (Fig. 2). Each method was assumed to minimize sample loss via one or more of the effects above. We placed all four types of grain structures at every site during 2013 (typically within 3 m of each other), but did not use the lid method in subsequent years because it was damaged regularly by passing trains.

Each of the screen, basket and box were designed to fit in the area between adjacent railway ties, and occupied an area of 120 × 60 cm (if screen) or 120 × 25 cm (if basket, box or lid; Fig. 2a). The lid occupied the same area as the basket and box, but was the only structure that was placed on the top of railway ties rather than on the ballast separating ties. The screen method consisted of a fiberglass screen (0.1 cm thickness) cut into a rectangle and placed directly on the ballast rock between two adjacent ties (Fig. 2b). The screen was secured to the adjacent ties with staples, and weighed down with six pieces of metal to reduce the potential for wind lifting the screen and scattering the grain. Being the simplest structure, the screen permitted foraging on grain by animals and removal by wind. The basket method (Fig. 2c) was comprised of a wooden frame which was lined with plastic netting on one side and then loosely filled with ballast rock. This frame was then placed on top of a wooden collection tray of the same area. The netting prevented the ballast rocks from falling into the collection tray where grain was expected to accumulate. Ballast rocks on the ground were excavated to a depth that allowed the basket to be placed with its top flush with the adjacent ties. The basket method reduced the potential for removal by wind, but was open at the top like the screen, permitting animals to forage on grain that had not trickled down.

The box and lid methods were modified versions of the basket that were intended to reduce losses to foraging

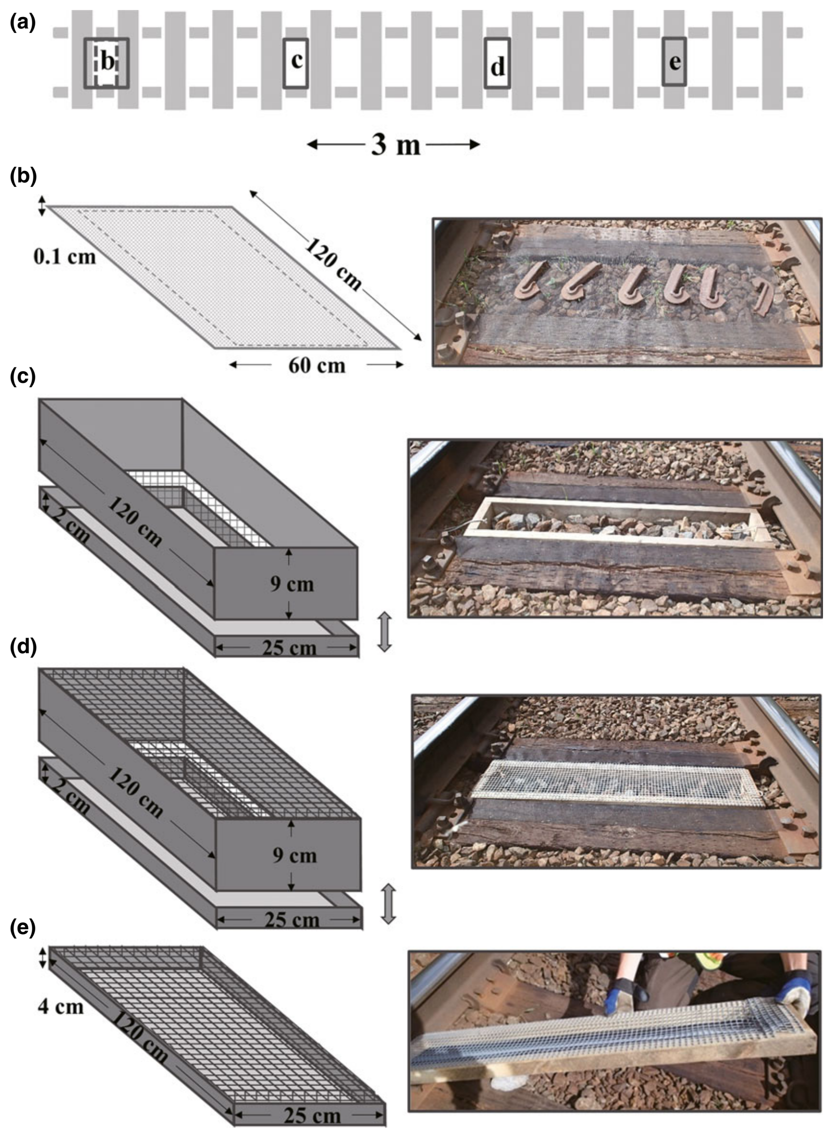

Figure 2 Position on railway track (a) and design of four different grain collection methods – (b) screen, (c) basket, (d) box and (e) lid – used to collect grain deposited by trains passing through Banff and Yoho National Parks between 2013 and 2015. Photo credit: Gregor Pachmann. [Colour figure can be viewed at wileyonlinelibrary.com]

animals and wind turbulence, but at the expense of greater deflection of falling grain from the structure itself. The design and placement of the box (Fig. 2d) was identical to the basket, except the upper frame that was covered with plastic hardware cloth (1.3 cm mesh; 19-gauge). The lid method (Fig. 2e) consisted of a wooden collection tray covered with a plastic hardware cloth (1.3 cm mesh; 19-gauge), and this structure was placed on top of a railway tie.

Grain collection and measurement

We visited each site every 2 weeks (mean = 14.1 days $\pm$ 2.7 SD) between April and October of 2013, 2014 and 2015 to collect grain deposited by passing trains. We also visited our sites at a similar frequency over the winter of November 2014 to March 2015. We collected samples from collection structures using a cordless wet/dry vacuum cleaner (De Walt DC515K, Baltimore, MD, USA). For baskets and boxes, we lifted and gently shook the entire structure to reduce the adherence of grain to ballast. We omitted from subsequent analyses, samples from structures that were damaged by wildlife or railway maintenance. Only the screen method was active during the winter period. When snow accumulated on top of the screen structures, we collected this snow as part of the sample, melted the snow and then processed the grain as for the rest of our samples.

Preliminary data indicated that sample weights were dependent on humidity and difficult to standardize via drying

because of variation in the rates of moisture loss and gain for different grain types and weather conditions. Consequently, we opted to count our samples by kernel, which we achieved by sorting each sample with a grain sieve (Can-Seed Equipment, Saskatoon, Saskatchewan, Canada) into each of the six grain types. For each sample and grain type, we used a high precision desktop seed counter (Elmor, C1, Schwyz, Switzerland) to generate a total seed count. We then converted these counts to weight using the following procedure. We collected 10 samples of each grain type, standardized the number of seeds in each, dried them in an oven at 130°C for 20 h and weighed them immediately after removal. We used the mean weight from the 10 samples as a conversion factor for that grain type (coefficients of variation ranged from 4.1 to 12.1% for different grain types; see Supporting Information).

Statistical modeling

We calculated deposition rates for each grain type (and also all grain types combined) by dividing the dry weight of grain obtained at each visit by the area of each collection structure (above) and by the number of days since the last visit, hence expressing each sample in units of g m^{-2} day^{-1}. We then modeled the natural log of this response variable (to ensure normality) via linear mixed-effects models as a function of four types of explanatory variables (Table 1; see also Supporting Information for values of these variables): variables describing the amount of grain transported, physical habitat and track conditions, characteristics of trains and variables that were specific to our study site (to control for their effect). We used sample site location and year as random effects.

For each combination of sampling method and grain type, we selected the best model using a forward selection procedure based on minimizing the Akaike information criterion (AIC). We did not use correlated variables ($|r_s| > 0.6$) in the same model, and tested for quadratic fits and interactions between variables. We conducted statistical modeling in R 3.1.3 (R Development Core Team, 2015) using the lme4 package (Bates *et al.*, 2014). We dropped 3, 2 and 1 outliers, respectively, from the canola samples of the basket, box and screen because these were likely to represent aberrant instances of large spills occurring on top of the structures.

Results

We collected 1979 samples consisting of 652, 614, 614 and 99 samples from screen, basket, box and lid methods respectively. Of the 1979 samples, 194, 1045, 707 and 33 samples were collected in the spring (March–May), summer (June–August), fall (September–October) and winter (November–February) respectively. The vast majority of samples appeared to result from slow trickles rather than spills. From April to October (when bears are most active), the monthly rate of deposition decreased and then increased (a pattern most apparent for basket, box and lid methods; Fig. 3a). There were no statistically significant differences between permanent and non-permanent sampling sites for the grain types with adequate samples: wheat [0.66 g (SD = 0.70) vs. 0.92 (SD = 0.90); $t = -0.96$, $P = 0.35$], canola [0.10 (SD = 0.07) vs. 0.19 (SD = 0.25); $t = -1.48$, $P = 0.15$] and lentils [0.15 (SD = 0.13) vs. 0.20 (SD = 0.17); $t = -0.95$, $P = 0.35$; Supporting Information]. Hence, our permanent sampling sites are likely representative of the study area.

Between 1 April and 31 October of 2013, 2014 and 2015, mean daily deposition rate (using the basket method) of all grain types together was 1.12 (SD = 1.23), 0.87 (SD = 0.71) and 2.75 (SD = 5.52) g m^{-2} day^{-1} respectively. Extrapolating these mean deposition rates across this period and for the 134 km length of the railway, *c*. 46.0, 35.6 and 112.8 tons of grain may have been deposited in Banff and Yoho between 1 April and 31 October of 2013, 2014 and 2015 respectively (mean = 64.8, SD = 41.9 tons over the three years) . Similarly, applying grain deposition rates from 1 November 2014 to 31 March 2015 derived from screens [1.52 (SD = 2.37) g m^{-2} day^{-1}], *c*. 44.6 tons of grain may have been available on the railway when bears emerged from their winter hibernation in April 2015. If these winter rates are representative of other years, *c*. 110 tons of grain may be deposited on average per year in Banff and Yoho.

Wheat, canola, peas, lentils, canary and flax constituted 46, 25, 18, 10, 1 and 1%, respectively, proportions by mass and deposition rates (Fig. 3b). Due to the small contribution of canary and flax to deposition, we restricted further analyses to wheat, canola, peas and lentils only. For these, the highest rates of deposition were recorded with the basket method, followed by the box, lid and screen (Fig. 3b). Relative to the mean deposition rate of all grain types in baskets, the box, lid and screen methods collected 77, 37 and 24% respectively. Due to the low number of samples collected with the lid method, we restricted statistical models to the basket, box and screen methods.

We ran 12 sets of linear mixed-effects models for the three grain collection methods and the four grain types, and then ran another three models for all grains together. Overall, temporal variables were selected more often than spatial variables. The best predictors of grain deposition were related to grain transportation (shipments and delivery), and were selected in 11 out of 12 models of individual grain types (Table 2). These models suggested that grain deposition increased with grain shipment or delivery at end ports [$\hat{\beta} = 0.14$ (SE = 0.06) to 1.10 (SE = 0.15)]. Site-specific variables occurred in 10 out of 12 models; of these, month of the year occurred in 10 models [$\hat{\beta} = -0.05$ (SE = 0.05) to -0.53 (SE = 0.07)]. Grain deposition decreased from January to the middle of the year, with an increase through fall and winter (quadratic coefficients from -0.10 [SE = 0.06] to 0.68 [SE = 0.08]).

Train characteristics were selected in seven out of 12 models, with a negative correlation with train speed [$\hat{\beta} = -0.15$ (SE = 0.08) to -0.26 (SE = 0.08)], but the opposite effect for canola collected using the box method ($\hat{\beta} = 0.20$ [SE = 0.07]). Physical habitat characteristics were the least selected variable type, occurring in only four of 12 models. Deposition increased with elevation [$\hat{\beta} = 0.21$

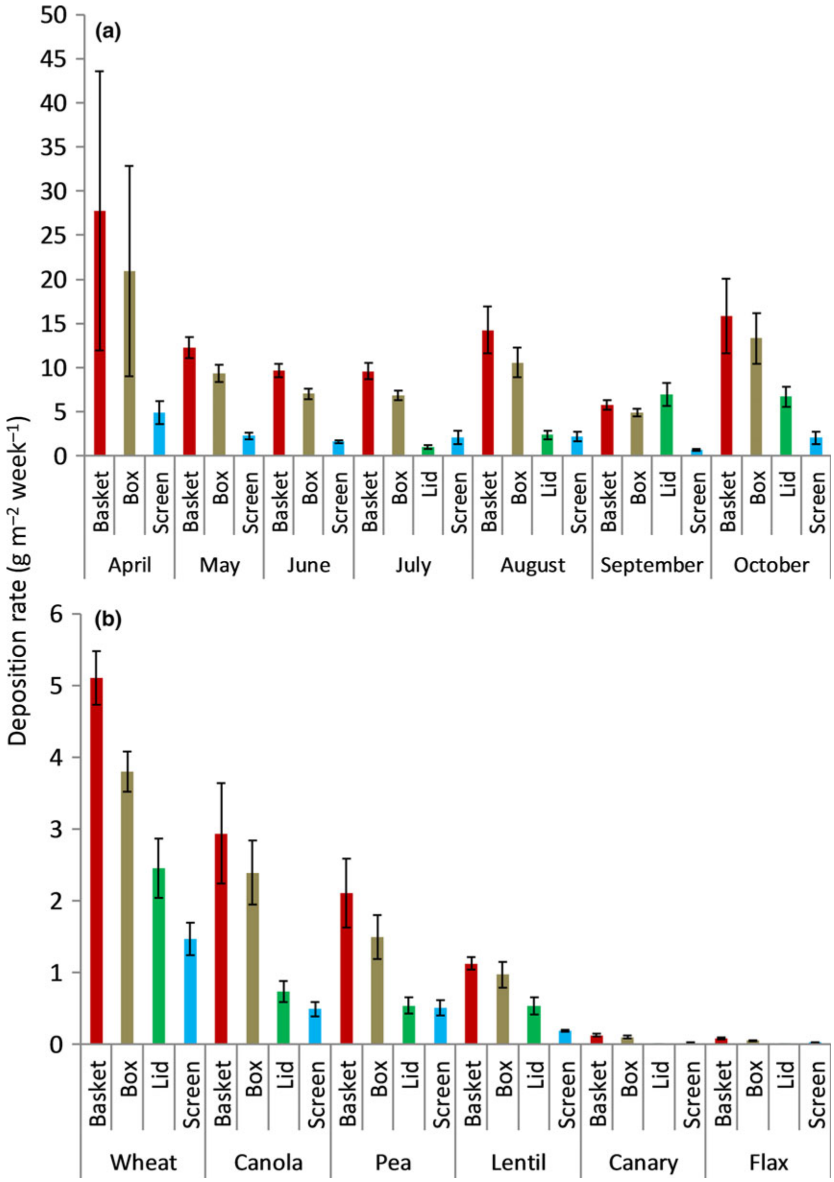

Figure 3 Mean monthly deposition rates of all six grain types deposited by trains passing through Banff and Yoho National Parks between 2013 and 2015 with standard errors (a), and mean weekly deposition rates with standard errors for each of six grain types (b) collected using four different methods (screen, basket, box and lid). [Colour figure can be viewed at wileyonlinelibrary.com]

(SE = 0.09) and 0.25 (SE = 0.07)] and track tortuosity [$\hat{\beta}$ = 0.13 (SE = 0.15) to 0.28 (SE = 0.10)] as predicted. Explanatory power was low due to high variance in deposition rates (mean marginal R^2 = 0.13 for all models; Table 2). Models that combined all grain types had especially low explanatory power, suggesting that deposition of each grain type is influenced by a different set of variables.

Discussion

Vehicles moving along ubiquitous transportation networks may deposit wildlife attractants and hence contribute to the risk of wildlife–vehicle collisions, but are rarely studied. Trains are currently the leading cause of mortality for grizzly bears in Banff and Yoho National Parks (Bertch & Gibeau, 2010), with a total of 19 collisions reported since 2000 (Parks Canada, unpubl. data). These collisions may greatly impact the persistence of this small population (50–73 adult animals; Sawaya *et al.*, 2012). Similar situations exist in other sites; for example, 42 brown bears were killed by traffic at a rate of 4.2 per year in Croatia (Huber *et al.*, 1998) and 29 were killed over 22 years by trains on a 109-km stretch in Montana, USA (Waller & Servheen, 2005).

Table 2 Model fit and beta coefficients (with standard errors) for variables from Table 1 that were selected in the best linear mixed-effects model for the deposition of wheat, canola, pea, lentils and all grain types combined, collected using three methods in Banff and Yoho National Parks between 2013 and 2015

		Grain transportation		Physical habitat		Train characteristics		Variables specific to the study site	
	$R^2_{Marginal}$ $R^2_{Conditional}$	Grain shipment	Grain delivery	Elevation	Track tortuosity	Measured train speed	Stoppage	Month	Days since check
Wheat									
Screen	0.28							−0.53 (0.07)	
	0.31	0.25 (0.06)				−0.26 (0.08)		0.41 (0.07)[a]	
Basket	0.17							−0.50 (0.05)	
	0.25	0.22 (0.06)		0.21 (0.09)				−0.10 (0.06)[a]	
Box	0.14							−0.50 (0.05)	
	0.15			0.25 (0.07)	0.18 (0.07)[b]				
Canola									
Screen	0.05							−0.05 (0.05)	
	0.22	0.17 (0.05)			0.12 (0.05)[c]		0.34 (0.15)	0.17 (0.06)	
Basket	0.11							−0.05 (0.05)	
	0.26	0.14 (0.06)						0.32 (0.05)[a]	−0.13 (0.05)
Box	0.11	0.56 (0.10)							
	0.28	−0.25 (0.09)[a]			0.19 (0.05)[b]	0.20 (0.05)			−0.14 (0.05)
Pea									
Screen	0.16							−0.14 (0.09)	
	0.18	0.26 (0.08)				−0.15 (0.08)		0.68 (0.08)[a]	
Basket	0.07		1.05 (0.18)						
	0.09		−0.38 (0.17)[a]					−0.29 (0.12)	
Box	0.11		1.10 (0.15)						
	0.12		−0.43 (0.15)[a]		0.28 (0.10)[b]				
Lentil									
Screen	0.14							−0.17 (0.07)	
	0.17		0.48 (0.07)			−0.21 (0.08)		0.23 (0.07)[a]	
Basket	0.14							−0.20 (0.07)	0.18 (0.07)
	0.22		0.70 (0.08)				0.93 (0.40)		
Box	0.10								0.20 (0.07)
	0.15		0.59 (0.08)				0.42 (0.39)		
All grain types combined[d]									
Screen	0.23							−0.12 (0.05)	
	0.30					−0.25 (0.05)		0.45 (0.05)	
Basket	0.08				−0.33 (0.12)			−0.15 (0.04)	
	0.19				0.24 (0.12)[a]	−0.18 (0.05)		0.07 (0.04)	
Box	0.03							−0.06 (0.04)	
	0.14					−0.11 (0.05)		0.08 (0.04)	

[a] Quadratic term.
[b] Within 200 m neighborhood.
[c] Within 100 m neighborhood.
[d] Grain transportation information could not be used when all grain types were combined together.

Six grain types were deposited in Banff and Yoho National Parks, at a mean rate of 1.64 g m^{-2} day^{-1} (SD = 3.60) from April to October of 2013, 2014 and 2015, and 1.52 g m^{-2} day^{-1} (SD = 2.37) from November 2014 to March 2015. An open container-like structure (basket method) captured the largest grain deposits in the snow-free period, but a simpler screen-based method was as effective at explaining variation among sites and could be used to estimate deposition rates in winter. Deposition rates were not well predicted by the variables that we used, and much of the variance in our samples remained unexplained. This suggests that occasional 'leaky' cars cause much of the variation in deposition rates.

If these mean deposition rates from sampled sites (sampled over 3 years for the April to October period and 1 year for the November to March period) are representative of the

entire railway (which appears so from our independent surveys in 2016), then on average 64.8 (SD = 41.9) tons are deposited along the entire railway from April to October (when bears are most active), and another 44.6 tons are deposited over winter (some of which may remain when snow melts in spring). The sum of the above quantities (110 tons for the entire year) is remarkably similar to a previous estimate of 112 tons (Dorsey, 2008), and equates to the load of *c.* 1.23 hopper cars (Gleim, 2014). This is a tiny quantity in comparison to the millions of tons and hundreds of thousands of hopper cars that service this area (Alberta Agriculture and Rural Development, 2013). Yet, even this volume could serve as a major food supplement for energy-stressed grizzly bears in a landscape that is generally deficient in resources (Garshelis, Gibeau & Herrero, 2005; López-Alfaro *et al.*, 2015).

To obtain a biological context for the energy supplement that this grain could potentially provide, we converted weight of spilled grain to energy equivalents. Based on our measured proportions of different grain types (assuming a 50–50 ratio for wheat–barley and pea–soy mixes), and their gross caloric values (Hullar *et al.*, 1999; Leterme, Montoya & Kish, 2006; Dourado *et al.*, 2011), 110 tons of grain is equivalent to *c.* 4.77×10^8 kcal of gross energy. This is equivalent to the entire annual caloric needs of 42–54 grizzly bears, based on average requirements during fall (30 576 kcal per day of digestible energy; Erlenbach *et al.*, 2014) or spring (24 072 kcal of digestible energy per day; Erlenbach *et al.*, 2014). While this figure is subject to many caveats (below), we note that the estimated regional population of grizzly bears is 50–73 animals (Sawaya *et al.*, 2012).

We caution that not all of this energy will be available or accessible to the bears because (1) digestible energy content of the grain is lower than our gross energy estimates, (2) grain is dispersed at low density over space and time, making it difficult to access and (3) grain is also consumed by other wildlife or may rot. Nevertheless, 43% of 85 grizzly bear scats that occurred within 150 m of the tracks (collected during May–October of 2012, 2013 and 2014) contained grain (M. Murray *et al.* unpublished data). We suspect that the peaks in bear mortality on the rail in spring and fall (Bertch & Gibeau, 2010) is associated with the accumulation of grain through the winter and subsequent melt in spring, and the higher shipping rates (and hence deposition) of grain in the fall (although bear use of anthropogenic linear features as movement corridors [e.g. Roever, Boyce & Stenhouse, 2010] may also contribute to mortality risk). Thus, spilled grain may supplement natural bear food similar to how garbage supplemented bear diets in earlier decades (Mattson, Blanchard & Knight, 1991). If so, the removal of this food source must be carefully planned so as to minimize the impact on survival and population viability. For example, the closure of garbage dumps in Yellowstone National Park of USA almost halved mean adult weight and decreased survival rates in the years that immediately followed (reviewed by Robbins, Schwartz & Felicetti, 2004).

Across methods, none of the variables we examined were powerful predictors, and a similar pattern was apparent in a smaller dataset collected from a subset of sites between October 2011 and March 2012 (Supporting Information). The most consistent predictor of grain deposition was very coarse information on grain shipping and receiving (statistics that were summarized for all of western Canada). As rail networks are less dense than road networks (Peterson & Church, 2008; Dulac, 2013), such broad-scale indices may serve as effective proxies for commodity transport on specific railway sections. However, our repeated temporal measurements on a small set of sites may have reduced our power to detect spatial variation (*sensu* Hurlbert, 1984) and contributed to the predominant selection of temporal variables in our models. To evaluate this possibility, we summed all samples collected within a year (for each grain type and collection method), and built models to predict total annual deposition. Although explanatory power remained modest for these models (marginal $R^2 = 0.13$), eight out of 12 models indicated that deposition was lower where measured train speed was higher [$\hat{\beta} = -0.12$ (SE = 0.07) to -0.36 (SE = 0.09); Supporting Information]. Consequently, higher spatial replication combined with year-round monitoring may help clarify the role of spatial predictors.

At a global level, we believe the problem of vehicle-borne food attractants will grow with the expanding network of railways and roadways (Dulac, 2013). Greater communication between grain shippers and wildlife managers might support schedule adjustments, to avoid shipping products that are highly palatable for a given species during times of high use by that species (e.g. during certain seasons; Steiner, Leisch & Hackländer, 2014 or during migration; Xia *et al.*, 2007). However, it may be difficult to predict hotspots and times of attractant deposition. Therefore, we recommend focusing on preventing this deposition from happening in the first place, such as by car maintenance (already occurred for some hopper cars in our study site; Dorsey, 2011), proactive reporting and cleaning of spills when they do occur (Bailleul *et al.*, 2012) and avoiding stopping trains overnight in wildlife areas.

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Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Appendix S1. Details of methodology for evaluating representativeness of permanent sample sites of other sites along railway.
Appendix S2. Volume and weight measurements for six types of grain.
Appendix S3. Summary statistics for variables that were used in modeling grain deposition
Appendix S4. Description of data collection and analysis for grain data during the winter of 2011.
Appendix S5. Model fit and beta coefficients (with standard errors) for variables that were selected in the best linear mixed-effects model for the deposition of wheat, canola, pea and lentils (summed over April-October for each of 2013, 2014 and 2015), collected using three methods.